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Koichiro TANAKA	)
Application No.: 10/721,075	) Examiner: Maria A. Elve
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For: LASER IRRADIATION APPARATUS,	)
LASER IRRADIATION METHOD,	)
AND METHOD FOR MANUFACTURING	)
A SEMICONDUCTOR DEVICE	)

VERIFICATION OF TRANSLATION

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Sir:

I, Ruka YASUOKA, C/O Semiconductor Energy Laboratory Co., Ltd. 398, Hase, Atsugi-shi, Kanagawa-ken 243-0036 Japan, a translator, herewith declare:

that I am well acquainted with both the Japanese and English Languages;

that I am the translator of the attached English translation of the Japanese Patent Application No. 2002-349007 filed on November 29, 2002; and

that to the best of my knowledge and belief the following is a true and correct English translation of the Japanese Patent Application No. 2002-349007 filed on November 29, 2002.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Date: this 14th day of December 2009

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[List of Attachment]

[Attachment]	Specification	1
[Attachment]	Drawing	1
[Attachment]	Abstract	1

[Proof] required

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[Title of the Invention] LASER IRRADIATION APPARATUS, LASER IRRADIATION METHOD, AND METHOD FOR MANUFACTURING A SEMICONDUCTOR DEVICE

[Claim 1]

A laser irradiation apparatus comprising:

a first laser oscillator oscillating first laser light having a wavelength at which an absorption coefficient to a processing object is 5×10^4 cm^{-1} or more in a pulsed manner;

means for controlling a shape and a position of a beam spot of the first laser light;

a second laser oscillator oscillating second laser light in a continuous manner;

means for controlling a shape and a position of a beam spot of the second laser light to overlap with the beam spot of the first laser light; and

means for controlling a relative position of the beam spot of the first laser light and the beam spot of the second laser light to the processing object.

[Claim 2]

A laser irradiation apparatus comprising:

a first laser oscillator oscillating first laser light having a wavelength included in visible light or a shorter wavelength than the visible light in a pulsed manner;

means for controlling a shape and a position of a beam spot of the first laser light;

a second laser oscillator oscillating second laser light in a continuous manner;

means for controlling a shape and a position of a beam spot of the second laser light to overlap with the beam spot of the first laser light; and

means for controlling a relative position of the beam spot of the first laser light and the beam spot of the second beam spot to a processing object.

[Claim 3]

A laser irradiation apparatus according to claim 1 or claim 2,

wherein the first laser light has a second harmonic.

[Claim 4]

A laser irradiation apparatus according to any one of claim 1 to claim 3,

wherein the second laser light has a fundamental wave.

[Claim 5]

A laser irradiation apparatus according to any one of claim 1 to claim 4,

wherein the beam spot of the first laser light has an elliptical shape, a rectangular shape, or a linear shape.

[Claim 6]

A laser irradiation apparatus according to any one of claim 1 to claim 5,

wherein the beam spot of the second laser light has an elliptical shape, a rectangular shape, or a linear shape.

[Claim 7]

A laser irradiation apparatus according to any one of claim 1 to claim 6, wherein the first laser oscillator is an Ar laser, a Kr laser, an excimer laser, a CO_2 laser, a YAG laser, a Y_2O_3 laser, a YVO_4 laser, a YLF laser, a $YalO_3$ laser, a glass laser, a ruby laser, an alexandrite laser, a Ti:sapphire laser, a copper vapor laser, or a gold vapor laser.

[Claim 8]

A laser irradiation apparatus according to any one of claim 1 to claim 7, wherein the second laser oscillator is an Ar laser, a Kr laser, a CO_2 laser, a YAG laser, a Y_2O_3 laser, a YVO_4 laser, a YLF laser, a $YalO_3$ laser, an alexandrite laser, a Ti:sapphire laser, or a helium-cadmium laser.

[Claim 9]

A laser irradiation apparatus according to any one of claim 1 to claim 8,

wherein: the processing object includes a substrate which has a thickness of d and has a transparent property to the first laser light; and

an incident angle $\phi1$ of the first laser light to a surface of the processing object satisfies

$\phi1 \geq \arctan(W1/2d)$

when W1 is defined as a length of a major axis or a minor axis of the beam spot of the first laser light.

[Claim 10]

A laser irradiation apparatus according to any one of claim 1 to claim 9,

wherein: the processing object includes a substrate which has a thickness of d and has a transparent property to the second laser light; and

an incident angle $\phi 2$ of the second laser light to the surface of the processing object satisfies

$\phi 2 \geq \arctan (W2/2d)$

when W2 is defined as a length of a major axis or a minor axis of the beam spot of the second laser light.

[Claim 11]

A laser irradiation method comprising the step of irradiating a processing object with first laser light oscillated in a pulsed manner and having a wavelength at which an absorption coefficient to the processing object is 5×10^4 cm^{-1} or more and second laser light oscillated in a continuous manner,

wherein when performing irradiation with the first and the second laser light, a beam spot formed on a surface of the processing object by the first laser light and a beam spot formed on the surface of the processing object by the second laser light are overlapped.

[Claim 12]

A laser irradiation method comprising the step of irradiating a processing object with first laser light oscillated in a pulsed manner and having a wavelength included in visible light or a shorter wavelength than the visible light and second laser light oscillated in a continuous manner,

wherein when performing irradiation with the first and the second laser light, a beam spot formed on a surface of the processing object by the first laser light and a beam spot formed on the surface of the processing object by the second laser light are overlapped.

[Claim 13]

A laser irradiation method according to claim 11 or claim 12,

wherein the first laser light has a second harmonic.

[Claim 14]

A laser irradiation method according to any one of claim 11 to claim 13,

wherein the second laser light has a fundamental wave.

[Claim 15]

A laser irradiation method according to any one of claim 11 to claim 14,

wherein the beam spot formed on the surface of the processing object by the first laser light has an elliptical shape, a rectangular shape, or a linear shape.

[Claim 16]

A laser irradiation method according to any one of claim 11 to claim 15,

wherein the beam spot formed on the surface of the processing object by the second laser light has an elliptical shape, a rectangular shape, or a linear shape.

[Claim 17]

A laser irradiation method according to any one of claim 11 to claim 16, wherein the first laser light is oscillated from a laser oscillator using an Ar laser, a Kr laser, an excimer laser, a CO_2 laser, a YAG laser, a Y_2O_3 laser, a YVO_4 laser, a YLF laser, a $YalO_3$ laser, a glass laser, a ruby laser, an alexandrite laser, a Ti:sapphire laser, a copper vapor laser, or a gold vapor laser.

[Claim 18]

A laser irradiation method according to any one of claim 11 to claim 17, wherein the second laser light is oscillated from a laser oscillator using an Ar laser, a Kr laser, a CO_2 laser, a YAG laser, a Y_2O_3 laser, a YVO_4 laser, a YLF laser, a $YalO_3$ laser, an alexandrite laser, a Ti:sapphire laser, or a helium-cadmium laser.

[Claim 19]

A laser irradiation method according to any one of claim 11 to claim 18,

wherein: the processing object includes a substrate having a thickness of d and has a transparent property to the first laser light; and

an incident angle $\phi 1$ of the first laser light to the surface of the processing object satisfies

$\phi 1 \geq \arctan(W1/2d)$

when W1 is defined as a length of a major axis or a minor axis of the beam spot formed on the surface of the processing object by the first laser light.

[Claim 20]

A laser irradiation method according to any one of claim 11 to claim 19,

wherein: the processing object includes a substrate having a thickness of d and

has a transparent property to the second laser light; and

an incident angle $\phi 2$ of the second laser light to the surface of the processing object satisfies

$\phi 2 \geq \arctan (W2/2d)$

when W2 is defined as a length of a major axis or a minor axis of the beam spot formed on the surface of the processing object by the second laser light.

[Claim 21]

A method for manufacturing a semiconductor device comprising the step of irradiating a semiconductor film formed on an insulating surface with first laser light oscillated in a pulsed manner and having a wavelength at which an absorption coefficient to the semiconductor film is 5×10^4 cm^{-1} or more and second laser light oscillated in a continuous manner to crystallize the semiconductor film,

wherein when performing irradiation with the first and the second laser light, a beam spot formed on a surface of the semiconductor film by the first laser light and a beam spot formed on the surface of the semiconductor film by the second laser light are overlapped.

[Claim 22]

A method for manufacturing a semiconductor device comprising the step of irradiating a semiconductor film formed on an insulating surface with first laser light oscillated in a pulse manner and having a wavelength included in visible light or a shorter wavelength than the visible light and second laser light oscillated in a continuous manner,

wherein when performing irradiation with the first and the second laser light, a beam spot formed on a surface of the semiconductor film by the first laser light and a beam spot formed on the surface of the semiconductor film by the second laser light are overlapped.

[Claim 23]

A method for manufacturing a semiconductor device according to claim 21 or claim 22,

wherein the first laser light has a second harmonic.

[Claim 24]

A method for manufacturing a semiconductor device according to any one of claim 21 to claim 23,

wherein the second laser light has a fundamental wave.

[Claim 25]

A method for manufacturing a semiconductor device according to any one of claim 21 to claim 24,

wherein the beam spot formed on the surface of the semiconductor film by the first laser light has an elliptical shape, a rectangular shape, or a linear shape.

[Claim 26]

A method for manufacturing a semiconductor device according to any one of claim 21 to claim 25,

wherein the beam spot formed on the surface of the semiconductor film by the second laser light has an elliptical shape, a rectangular shape, or a linear shape.

[Claim 27]

A method for manufacturing a semiconductor device according to any one of claim 21 to claim 26, wherein the first laser light is oscillated from a laser oscillator using an Ar laser, a Kr laser, an excimer laser, a CO_2 laser, a YAG laser, a Y_2O_3 laser, a YVO_4 laser, a YLF laser, a $YalO_3$ laser, a glass laser, a ruby laser, an alexandrite laser, a Ti:sapphire laser, a copper vapor laser, or a gold vapor laser.

[Claim 28]

A method for manufacturing a semiconductor device according to any one of claim 21 to claim 27, wherein the second laser light is oscillated from a laser oscillator using an Ar laser, a Kr laser, a CO_2 laser, a YAG laser, a Y_2O_3 laser, a YVO_4 laser, a YLF laser, a $YalO_3$ laser, an alexandrite laser, a Ti:sapphire laser, or a helium-cadmium laser.

[Claim 29]

A method for manufacturing a semiconductor device according to any one of claim 21 to claim 28,

wherein: the semiconductor film is formed over a substrate having an insulating surface, having a thickness of d, and having a transparent property to the first laser light; and

an incident angle $\phi 1$ of the first laser light to the surface of the semiconductor

film satisfies

$\phi 1 \geq \arctan(W1/2d)$

when W1 is defined as a length of a major axis or a minor axis of the beam spot formed on the surface of the semiconductor film by the first laser light.

[Claim 30]

A method for manufacturing a semiconductor device according to any one of claim 21 to claim 29,

wherein: the semiconductor film is formed over a substrate having an insulating surface, having a thickness of d, and having a transparent property to the first laser light; and

an incident angle $\phi 2$ of the second laser light to the surface of the semiconductor film satisfies

$\phi 2 \geq \arctan(W2/2d)$

when W2 is defined as a length of a major axis or a minor axis of the beam spot formed on the surface of the semiconductor film by the second laser light.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention Pertains]

The present invention relates to a laser irradiation apparatus utilized for crystallizing a semiconductor film. Moreover, the present invention relates to a laser irradiation method and a method for manufacturing a semiconductor device which use the laser irradiation apparatus.

[0002]

[Conventional Art]

A thin film transistor using a poly-crystalline semiconductor film (poly-crystalline TFT) has advantages that the mobility thereof is higher than that of a TFT using an amorphous semiconductor film by two or more digits, and a pixel portion and a peripheral driver circuit thereof in a semiconductor display device can be formed together over the same substrate. The poly-crystalline semiconductor film can be formed over an inexpensive glass substrate by employing a laser annealing method.

[0003]

Lasers are roughly classified into two types of pulse oscillation and continuous oscillation. The output energy of laser light per unit time of a pulse oscillation laser, typically an excimer laser, is higher than that of a continuous oscillation laser by triple ~ six digits. Therefore, throughput can be enhanced by shaping a beam spot (a region, in a surface of a processing object, which is irradiated with laser light in fact) into a rectangular shape with several centimeters on each side or a linear shape with 100 mm or more in length through an optical system and irradiating a semiconductor film with the laser light efficiently. As a result, using the pulse oscillation lasers has been becoming the mainstream in crystallization of a semiconductor film.

[0004]

It is noted that a "linear shape" here does not mean a "line" in a strict sense but means a rectangle (or a long ellipse) with a large aspect ratio. For example, although something with an aspect ratio of two or more (preferably, 10 ~ 10000) is referred to as a linear shape, the fact that the linear shape is included in the rectangular shape is not changed.

[0005]

However, a semiconductor film crystallized by using pulse oscillation laser light as described above is formed from a plurality of crystal grains assembled and the position and the size of the crystal grains are random. Compared with an inside of the crystal grain, an interface between the crystal grains (crystal grain boundary) has an infinite number of recombination centers and trapping centers existing due to an amorphous structure and crystal defects. There is a problem in that when a carrier is trapped in this trapping center, potential of the crystal grain boundary increases to become a barrier against the carrier, and a current-transporting property of the carrier is deteriorated.

[0006]

In view of the above problem, recently, attention has been paid to a technique in which a semiconductor film is irradiated with a continuous oscillation laser while being scanned with the continuous oscillation laser in one direction to grow crystals continuously toward a scanning direction so as to form assembled crystal grains formed from single crystals extending long along the scanning direction. It is considered that

the above technique enables to form a semiconductor film in which almost no crystal grain boundary is present at least in a channel direction of a TFT.

[0007]

By the way, it is preferable that the absorption coefficient of the laser light to the semiconductor film be high in order to crystallize the semiconductor film more efficiently. The absorption coefficient differs depending on the material and the thickness of the semiconductor film. In the case of using a YAG laser or a YVO_4 laser to crystallize a silicon film having a thickness of several tens ~ several hundreds nm which is generally used for a semiconductor device, a second harmonic which has a shorter wavelength than a fundamental wave is higher in absorption coefficient, and crystallization can be performed efficiently.

[0008]

However, the energy of the laser light converted into a harmonic is lower than that of a fundamental wave. Therefore, it is difficult to enhance throughput by enlarging the area of the beam spot. Especially, since the output energy of the laser light of the continuous oscillation laser per unit time is lower than that of the pulse oscillation laser, this tendency is remarkable. For example, when a Nd:YAG laser is used, the conversion efficiency from a fundamental wave (wavelength: 1064 nm) to a second harmonic (wavelength: 532 nm) is about 50 %. Moreover, the resistance of a non-linear optical element which performs conversion into a harmonic against the laser light is extremely low; therefore, for example, the continuous oscillation YAG laser can output a fundamental wave of 10 kW, while an output energy of only about 10 W of a second harmonic can be obtained. Therefore, in order to obtain necessary energy density for crystallizing the semiconductor film, the area of the beam spot must be narrowed to about 10^{-3} mm^2; thus, it is inferior to the pulse oscillation excimer laser in terms of throughput.

[0009]

It is noted that in both ends of the beam spot in the direction perpendicular to the scanning direction, a region where the crystal grain is extremely small and whose crystallinity is inferior to the center of the beam spot is formed. Even when a semiconductor element is formed in this region, a high characteristic cannot be expected.

Therefore, it is important to reduce the proportion of the region where the crystallinity is inferior in the whole region which is irradiated with the laser light in order to ease the restriction in the layout of the semiconductor element.

[0010]

[Problems to be Solved by the Invention]

In view of the problem described above, it is an object of the present invention to provide a laser irradiation apparatus for enlarging an area of a beam spot and reducing the proportion of a region where the crystallinity is low. In addition, it is also an object of the present invention to provide a laser irradiation apparatus for enhancing throughput with use of continuous oscillation laser light. Furthermore, it is an object of the present invention to provide a laser irradiation method and a method for manufacturing a semiconductor device which use the laser irradiation apparatus.

[0011]

[Means for Solving the Problems]

According to the laser irradiation method of the present invention, a region melted by pulse oscillation first laser light of a harmonic is irradiated with continuous oscillation second laser light. Specifically, the first laser light has a wavelength which is approximately equal to or shorter than that of visible light (approximately 830 nm or less). Since the first laser light melts a semiconductor film, the absorption coefficient of the second laser light to the semiconductor film increases drastically and the second laser light becomes easy to be absorbed by the semiconductor film.

[0012]

FIG. 8 shows a relationship between the wavelength (nm) of the laser light and the absorption coefficient (cm^{-1}) of an amorphous silicon film (amorphous silicon). When the absorption coefficient is 5×10^4 cm^{-1} or more, it is considered that the first laser light can melt the semiconductor film thoroughly. In order to obtain the absorption coefficient in this range of value, in the case of the amorphous silicon film, it is considered that it is desirable that the first laser light have a wavelength of 830 nm or less. It is noted that the relationship between the wavelength of the first laser light and the absorption coefficient differs depending on the material, crystallinity, or the like of the semiconductor film. Therefore, the wavelength of the first laser light is not limited

to this, and the wavelength of the first laser light may be determined as appropriate so that the absorption coefficient becomes 5×10^4 cm^{-1} or more.

[0013]

Further, the laser irradiation apparatus of the present invention includes: a first laser oscillator oscillating first laser light with a wavelength of visible light or a shorter wavelength than visible light in a pulsed manner; and a second laser oscillator oscillating second laser light which is a fundamental wave in a continuous manner. The shapes and the positions of a beam spot of the first laser light and a beam spot of the second laser light are controlled by a first and a second optical system respectively. Further, the beam spots of the first laser light and the second laser light are overlapped with each other by the above two optical systems. In addition, the laser irradiation apparatus of the present invention includes a means for controlling the relative positions of the beam spot of the first laser light and the beam spot of the second laser light with respect to the processing object.

[0014]

Thus, a portion which is melted by the first laser light moves in the semiconductor film while keeping its melting state by irradiation with the second laser light which is continuous oscillation. Therefore, crystal grains growing continuously toward a scanning direction are formed. By forming single-crystal grains extending long along the scanning direction, a semiconductor film in which almost no crystal grain boundary is present at least in a channel direction of a TFT can be formed.

[0015]

The time for which the melting state can be kept depends on the balance between the output of the pulse oscillation laser and the output of the continuous oscillation laser. When the semiconductor film is irradiated with the next pulse oscillation laser within the time for which the melting state can be kept, the annealing of the semiconductor film can be continued as keeping the above melting state. In the extreme case, a condition can be employed in which once the semiconductor film is melted by the pulse laser, only irradiation with a fundamental wave is enough to keep its melting state. In this case, after irradiation with the pulse laser is performed for only one shot, the melting state may be kept by the continuous oscillation laser.

[0016]

It is noted that the higher harmonic has the lower energy. Therefore, when the first laser light has a wavelength of a fundamental wave of 1 μm approximately, a second harmonic is the most desirable. However, the present invention is not limited to this, and the first laser light is acceptable as long as it has a wavelength of visible light or a shorter wavelength than visible light. In addition, because of the purpose of the aid of the energy to the first laser light, the output output power of the second laser light is emphasized rather than the absorption coefficient to the semiconductor film. Therefore, it is the most desirable that a fundamental wave be used for the second laser light. However, the present invention is not limited to this, and the second laser light may be either a fundamental wave or a harmonic.

[0017]

When a fundamental wave is employed for the second laser light, it is not necessary to convert the wavelength, so that the energy does not need to be suppressed in consideration of the deterioration of a non-linear optical element. For example, it is possible that the second laser light has an output 100 times or more (1000 W or more, for example) the output of the continuous oscillation laser having a wavelength of visible light or a shorter wavelength than visible light. Therefore, cumbersomeness of maintenance of the non-linear optical element disappears and the total energy of the laser light absorbed by the semiconductor film can be increased so that the larger crystal grain can be obtained.

[0018]

Moreover, the energy per unit time of the oscillated laser light of the pulse oscillation is higher than that of the continuous oscillation. In addition, when a harmonic and a fundamental wave are compared, the energy of the harmonic is lower, and the energy of the fundamental wave is higher. In the present invention, the laser light having a harmonic or having a wavelength of visible light or a shorter wavelength than visible light is the pulse oscillation and the laser light of a fundamental wave is the continuous oscillation. Thus, the size of a region in which a beam spot of a harmonic and a beam spot of a fundamental wave are overlapped with each other can be ensured as compared with the structure in which both the harmonic and the fundamental wave are the continuous oscillation, and the structure in which the harmonic is the continuous oscillation while the fundamental wave is the pulse oscillation.

[0019]

For example, an overlapping of two beam spots formed by two lasers is explained by exemplifying a continuous oscillation YAG laser and a pulse oscillation excimer laser.

[0020]

FIG. 1(A) shows an aspect in which a beam spot 10 of the continuous oscillation YAG laser having a fundamental wave and a beam spot 11 of the continuous oscillation YAG laser having a second harmonic are overlapped. The YAG laser of a fundamental wave can obtain an output energy of 10 kW approximately. On the other hand, the YAG laser of a second harmonic can obtain an output energy of 10 W approximately.

[0021]

When 100 % of the energy of the laser light is assumed to be absorbed by the semiconductor film, it is possible to enhance crystallinity of the semiconductor film by setting the energy density of each laser light at 0.01 ~ 100 MW/cm^2. Therefore, here, the energy density is set at 1 MW/cm^2.

[0022]

Then, when it is assumed that the shape of the beam spot 10 of the continuous oscillation YAG laser having a fundamental wave is rectangular, the length in a direction of the minor axis is L_{X1}, and the length in a direction of the major axis is L_{Y1}, in order to satisfy the energy density described above, L_{X1} is set to be 20 μm ~ 100 μm. For example, it is appropriate that when L_{X1} = 20 μm, L_{Y1} = 50 mm approximately, and when L_{X1} = 30 μm, L_{Y1} = 30 mm approximately.

[0023]

On the other hand, when it is assumed that the shape of the beam spot 11 of the continuous oscillation YAG laser having a harmonic is rectangular, the length in a direction of the minor axis is L_{X2}, and the length in a direction of the major axis is L_{Y2}, in order to satisfy the energy density described above, L_{X2} is set to be 20 μm ~ 100 μm. For example, it is appropriate that when L_{X2} = 10 μm, L_{Y2} = 100 μm approximately.

[0024]

The area of the region in which the beam spot 10 of the continuous oscillation

YAG laser having a fundamental wave and the beam spot 11 of the continuous oscillation YAG laser having a second harmonic are overlapped corresponds to the area of the beam spot 11 when it is assumed that the beam spot 11 completely overlap the beam spot 10.

[0025]

Next, FIG. 1(B) shows an aspect in which the beam spot 10 of the continuous oscillation YAG laser having a fundamental wave and a beam spot 12 of the pulse oscillation excimer laser are overlapped. The pulse oscillation excimer laser can obtain an output energy of approximately 1 J per a pulse. Note that, when the pulse width is set to be 30 ns approximately, the output per unit time is 30 MW. Therefore, when it is assumed that the shape of the beam spot 12 of the pulse oscillation excimer laser is rectangular, the length in a direction of the minor axis is L_{X3}, and the length in a direction of the major axis is L_{Y3}, in order to satisfy the energy density described above, L_{X3} is set to be 20 μm ~ 500 μm. For example, it is appropriate that when L_{X3} = 400 μm, L_{Y2} = 300 mm approximately.

[0026]

The area of the region in which the beam spot 10 of the continuous oscillation YAG laser having a fundamental wave and the beam spot 12 of the pulse oscillation excimer laser are overlapped corresponds to the area of the beam spot 10 when it is assumed that the beam spot 10 completely overlap the beam spot 12.

[0027]

Therefore, in the case where the first laser light is continuous oscillation and the second laser light is pulse oscillation according to the present invention, the area in which the two laser light are overlapped can be considerably enlarged, and throughput can be more enhanced as compared with the case where both the first laser light and the second laser light are continuous oscillation as shown in FIG. 1(A).

[0028]

It is noted that the laser light is not limited to two as long as it is two or more. A plurality of the first laser light having a harmonic may be used. A plurality of the second laser light may be used.

[0029]

It is noted that by making the beam spot have a linear shape, the width of the beam spot in the direction of the major axis in the region where the crystal grains which are crystallized in the scanning direction are assembled can be made as broad as possible. That is to say, it can be said that in the whole beam spot, the proportion of the area of the region where the crystallinity is low formed in both ends of the major axis can be decreased. In the present invention, however, the shape of the beam spot is not limited to a linear shape, but it does not lead to any problems even if the shape is rectangular or planar as long as the sufficient annealing can be performed on the object to be irradiated.

[0030]

It is noted that the first laser light can be obtained by using an Ar laser, a Kr laser, an excimer laser, a CO_2 laser, a YAG laser, a Y_2O_3 laser, a YVO_4 laser, a YLF laser, a $YalO_3$ laser, a glass laser, a ruby laser, an alexandrite laser, a Ti:sapphire laser, a copper vapor laser or a gold vapor laser which is pulse oscillation.

[0031]

In addition, the second laser light can be obtained by using an Ar laser, a Kr laser, a CO_2 laser, a YAG laser, a Y_2O_3 laser, a YVO_4 laser, a YLF laser, a $YalO_3$ laser, an alexandrite laser, a Ti:sapphire laser or a helium-cadmium laser which is continuous oscillation.

[0032]

It is noted that in the process for crystallizing the semiconductor film with the continuous oscillation laser, throughput can be enhanced by processing the beam spot into an elliptical shape or a rectangular shape extending long in one direction and scanning it in the direction of the minor axis of the beam spot to crystallize the semiconductor film. The shape of the laser beam after processing becomes an elliptical shape because the original shape of the laser light is circular or a near-circular shape. When the original shape of the laser light is rectangular, after it is processed to have a longer major axis further by being enlarged in one direction through a cylindrical lens or the like, it may be used. In addition, a plurality of laser beams are each processed into an elliptical shape or a rectangular shape extending long in one direction, and they are made to be chained in one direction so as to form a longer beam in order to enhance throughput.

[0033]

[Embodiment Mode of the Invention]

(Embodiment Mode 1)

The structure of the laser irradiation apparatus of the present invention is explained by using FIG. 2.

[0034]

101 denotes a pulse oscillation laser oscillator, and a 6 W Nd:YLF laser is used in this embodiment mode. The laser oscillator 101 has a TEM_{00} oscillation mode and conversion into a second harmonic is performed by a non-linear optical element. It is not necessary to particularly limit to a second harmonic; however, in terms of the energy efficiency, a second harmonic is superior to other higher harmonics. The frequency is 1 kHz and the pulse width is 60 ns approximately. In this embodiment mode, a solid laser that has an output of 6 W approximately is used, but a large-scaled laser that outputs as much as 300 W, for example a XeCl excimer laser, may also be employed.

[0035]

It is noted that the non-linear optical element may be provided inside a resonator included in the oscillator or a resonator equipped with the non-linear optical element separately may be provided outside the oscillator of a fundamental wave. The former has an advantage that the apparatus can be made small and the accurate control of the length of the resonator is not necessary any more. The latter has an advantage that the interaction of a fundamental wave and a harmonic can be ignored.

[0036]

For the non-linear optical element, a crystal whose non-linear optical constant is relatively large such as KTP ($KTiOPO_4$), BBO (β-BaB_2O_4), LBO (LiB_3O_5), CLBO ($CsLiB_6O_{10}$), GdYCOB ($YCa_4O(BO_3)_3$), KDP (KD_2PO_4), KB5, $LiNbO_3$, $Ba_2NaNb_5O_{15}$ or the like is used. Especially, by using LBO, BBO, KDP, KTP, KB5, CLBO or the like, conversion efficiency from a fundamental wave into a harmonic can be enhanced.

[0037]

Since the laser light is generally emitted in a horizontal direction, the traveling direction of the first laser light oscillated from the laser oscillator 101 is changed by a

reflecting mirror 102 to a direction which has an angle (incident angle) of $\theta 1$ from a vertical direction. In this embodiment mode, $\theta 1 = 21°$. The shape of the beam spot of the first laser light whose traveling direction is changed is processed by a lens 103, and a processing object 104 is irradiated therewith. In FIG. 2, the reflecting mirror 102 and the lens 103 correspond to an optical system that controls the shape and the position of the beam spot of the first laser light.

[0038]

In FIG. 2, a planoconcave cylindrical lens 103a and a planoconvex cylindrical lens 103b are used as the lens 103.

[0039]

The planoconcave cylindrical lens 103a has a radius of curvature of 10 mm and a thickness of 2 mm and is arranged in the position 29 mm away from the surface of the processing object 104 along the optical axis when the traveling direction of the first laser light is assumed to be the optical axis. Further, the generating line of the planoconcave cylindrical lens 103a is made to be perpendicular to the incident plane of the first laser light which enters the processing object 104.

[0040]

The planoconvex cylindrical lens 103b has a radius of curvature of 15 mm and a thickness of 2 mm and is arranged in the position 24 mm away from the surface of the processing object 104 along the optical axis. Further, the generating line of the planoconvex cylindrical lens 103b is made to be parallel to the incident plane of the first laser light which enters the processing object 104.

[0041]

Thus, a first beam spot 106 having a size of 3×0.2 mm is formed in the processing object 104.

[0042]

Moreover, 110 denotes a continuous oscillation laser oscillator, and a 2 kW Nd:YAG laser of a fundamental wave is used in this embodiment mode. The second laser light oscillated from the laser oscillator 110 is transmitted by an optical fiber 111 of $\phi 300$ μm. The optical fiber 111 is arranged so that the exit thereof has an angle of $\theta 2$ to the vertical direction. In this embodiment mode, $\theta 2 = 45°$. In addition, the exit

of the optical fiber 111 is arranged in the position 105 mm away from the processing object 104 along the optical axis of the second laser light emitted from the laser oscillator 110 and the optical axis thereof is made to be included in the incident plane.

[0043]

The shape of the beam spot of the second laser light emitted from the optical fiber 111 is changed by a lens 112 and the processing object 104 is irradiated therewith. In FIG. 2, the optical fiber 111 and the lens 112 correspond to an optical system which controls the shape and the position of the beam spot of the second laser light.

[0044]

In FIG. 2, a planoconvex cylindrical lens 112a and a planoconvex cylindrical lens 112b are used as the lens 113.

[0045]

The planoconvex cylindrical lens 112a has a radius of curvature of 15 mm and a thickness of 4 mm, and is arranged in the position 85 mm away from the surface of the processing object 104 along the optical axis of the second laser light. The direction of the generating line of the planoconvex cylindrical lens 112a is made to be perpendicular to the incident plane.

[0046]

The planoconvex cylindrical lens 112b has a radius of curvature of 10 mm and a thickness of 2 mm, and is arranged in the position 25 mm away from the surface of processing object 104 along the optical axis of the second laser light.

[0047]

Thus, a second beam spot 105 with a size of 3×0.1 mm is formed in the processing object 104.

[0048]

In this embodiment mode, a substrate over which a semiconductor film is formed is arranged as the processing object 104 so as to be parallel to the horizontal plane. The semiconductor film is formed on the surface of a glass substrate, for example. The substrate over which the semiconductor film is formed is a glass substrate having a thickness of 0.7 mm, which is fixed on an absorption stage 107 in order that the substrate does not fall down in laser irradiation.

[0049]

The absorption stage 107 is able to move in XY directions in the plane parallel to the processing object 104 by a uniaxial robot 108 for the X axis and a uniaxial robot 109 for the Y axis.

[0050]

It is noted that in the case of annealing the semiconductor film formed over the substrate which has a transparent property to the laser light, in order to realize the uniform irradiation with the laser light, when an incident plane is defined as one which is a flat plane perpendicular to the surface to be irradiated and which is one of a plane including a shorter side and a plane including a longer side when regarding the shape of the beam as a rectangular shape, it is desirable that an incident angle ϕ of the laser light satisfies $\phi \geq \arctan(W/2d)$ where a length of the longer side or the shorter side included in the incident plane is W; and a thickness of the substrate having a transparent property to the laser light and placed on the surface to be irradiated is d. In the case of using a plurality of laser light, this argument needs to be satisfied with respect to each laser light. It is noted that when the track of the laser light is not present on the incident plane, the incident angle of the incident plane to which the track is projected is ϕ. When the laser light enters at this incident angle ϕ, it is possible to perform uniform irradiation with the laser light without interference of reflected light on the surface of the substrate with reflected light from a rear surface of the substrate. The above argument is considered assuming that a refractive index of the substrate is 1. In fact, the substrate mostly has a refractive index of about 1.5, and a larger calculated value than the angle calculated in accordance with the argument is obtained when considering this value. However, since the energy of the beam spot is attenuated toward an end of the beam spot, the interference in this portion does not occur so much, and the effect of attenuating interference can be sufficiently obtained using the above calculated value. This argument is applied to both of the first laser light and the second laser light and it is preferable that both of them satisfy the inequality. However, a problem does not arise even if the above inequality is not satisfied as for a laser whose coherent length is extremely short, for example an excimer laser. The above inequality related to ϕ is applied only when the substrate has a transparent property to the laser light.

[0051]

Generally, a glass substrate has a transparent property to a fundamental wave whose wavelength is about 1 μm, and to a green second harmonic. In order that this lens satisfies the inequality, the positions of the planoconvex cylindrical lens 103b and the planoconvex cylindrical lens 112b are displaced in the perpendicular direction to the incident plane so as to have incident angles of $\phi 1$ and $\phi 2$ in the plane perpendicular to the surface of the processing object 104 including the minor axis of the beam spot. In this case, the interference does not occur when the first beam spot 106 has a slope of $\phi 1=10°$, and the second beam spot 105 has a slope of $\phi 2=5°$ approximately.

[0052]

Note that it is preferable that the first laser light and the second laser light be TEM_{00} mode (single mode) obtained from a stable resonator. In the case of TEM_{00} mode, since the laser light has the Gaussian intensity distribution and is superior in a light-condensing property, it is easy to process the beam spot.

[0053]

When the substrate over which the semiconductor film is formed is used as the processing object 104, for example, a silicon oxynitride film is formed with a thickness of 200 nm on one surface of a glass substrate having a thickness of 0.7 mm and an amorphous silicon (a-Si) film is formed with a thickness of 70 nm on it as a semiconductor film by using a plasma CVD method. In addition, in order to improve resistance of the semiconductor film against the laser, thermal annealing is performed on the amorphous silicon film at 500 °C for an hour. In addition to the thermal annealing, crystallization utilizing a catalytic metal may be performed. An optimum condition in irradiation with laser light is almost the same either for the semiconductor film on which the thermal annealing is performed or for the semiconductor film crystallized by using a metal catalyst.

[0054]

Then, the processing object 104 (the substrate over which the semiconductor film is formed) is scanned in the direction of the minor axis of the second beam spot 105 by using the Y-axis robot 109. At this time, the output of both the laser oscillators 101, 102 are specification values. By this scanning of the processing object 104, the first beam spot 106 and the second beam spot 105 are scanned relatively to the surface

of the processing object 104.

[0055]

Since the semiconductor film in a region of the first beam spot 106 melts, the absorption coefficient of the continuous oscillation second laser light to the semiconductor film increases considerably. Therefore, in the region which has a width of 1 ~ 2 mm, corresponds to the major axis of the second beam spot 105, and extends in the scanning direction, single-crystal grains in which crystals grow in the scanning direction are formed in a packed state.

[0056]

It is noted that, in the semiconductor film, in the region where irradiation is performed with the first beam spot 106 and the second beam spot 105 overlapped, the state where the absorption coefficient is increased by the first laser light of a second harmonic is kept by the first laser light which is a fundamental wave. Therefore, even after irradiation with the first laser light of a second harmonic stops, the state where the semiconductor film is melted and the absorption coefficient is increased is kept by the first laser light which is a fundamental wave. Therefore, even after irradiation with the first laser light of a second harmonic stops, the melted region where the absorption coefficient is increased can be moved in one direction to some extent by the scanning, and thus crystal grains growing toward the scanning direction are formed. Further, in order to keep the region where the absorption coefficient is increased during the process of the scanning continuously, it is desirable that irradiation with the first laser light of a second harmonic be performed again to compensate the energy.

[0057]

Note that it is appropriate that the scanning speed of the first beam spot 106 and the second beam spot 105 is about several cm/s ~ several hundreds cm/s, and here it is set to 50 cm/s.

[0058]

Next, FIG. 3 shows the scanning route of the first beam spot 106 and the second beam spot 105 on the surface of the processing object 104. In the case where irradiation with the second laser light is performed on the whole surface of the semiconductor film, that is the processing object 104, after the scanning in one direction

is performed with the Y-axis robot 109, the first beam spot 106 and the second beam spot 105 are slid with the X-axis robot 108 in the direction perpendicular to the scanning direction by the Y-axis robot 109.

[0059]

For example, the semiconductor film is scanned in one direction at a scanning speed of 50 cm/s by the the Y-axis robot 109. In FIG. 3, the scanning route is indicated by A1. Then, the scanning route of the first beam spot 106 and the second beam spot 105 is slid in the direction perpendicular to the A1 by the X-axis robot 108. The scanning route by the sliding is indicated by B1. Next, the semiconductor film is scanned in one direction opposite to the scanning route A1 with the Y-axis robot 109. This scanning route is indicated by A2. Next, the scanning route of the first beam spot 106 and the second beam spot 105 is slid in the direction perpendicular to the A2 by the X-axis robot 108. The scanning route by the sliding is indicated by B2. In this manner, by repeating the scanning with the Y-axis robot 109 and the scanning with the X-axis robot 108 in order, irradiation with the second laser light or the first laser light can be performed on the whole surface of the processing object 104.

[0060]

It is desirable that the length of the scanning routes B1, B2 ··· be for a width of 1 ~ 2 mm that corresponds to the major axis of the second beam spot 105.

[0061]

The region which is irradiated with the second laser light and in which the crystal grains growing in the scanning direction are formed has very high crystallinity. Therefore, when the region is employed as a channel forming region of a TFT, very high electrical mobility and on-current can be expected. However, in the case where a portion which does not need such high crystallinity exists in the semiconductor film, irradiation with the laser light is not needed to be performed on the portion. Alternatively, irradiation with the laser light may be performed under conditions where high crystallinity is not obtained by increasing the scanning speed, for example. When the scanning is performed at a speed of, for example, 2 m/s approximately, the a-Si film can be crystallized but it is difficult to form a region where crystallization is continuously performed in the scanning direction as described above. Moreover, by

increasing the scanning speed partially, throughput can be further enhanced.

[0062]

It is noted that, for scanning with laser light, there are the following: an irradiation system moving type in which an irradiation position of laser light is moved while a substrate as a processing object is fixed; a processing object moving type in which a substrate is moved while an irradiation position of laser light is fixed; and a method in which the above two methods are combined. Since the laser irradiation apparatus of the present invention uses at least two laser light of the first laser light and the second laser light, it is appropriate to employ the processing object moving type which can simplify the structure of an optical system the most. However, the laser irradiation apparatus of the present invention is not limited to this, and it is not impossible to employ the irradiation system moving type or combine the processing object moving type and the irradiation system moving type by devising the optical system. In any cases, it is premised that the moving direction of each beam spot relative to the semiconductor film can be controlled.

[0063]

It is noted that the optical system in the laser irradiation apparatus of the present invention is not limited to the structure shown in this embodiment mode.

[0064]

(Embodiment Mode 2)

Next, the laser light irradiation method and the method for manufacturing a semiconductor device of the present invention are explained with FIG. 3.

[0065]

First of all, a base film 501 is formed on a substrate 500 as shown in FIG. 4(A). A glass substrate such as barium borosilicate glass or aluminoborosilicate glass, a quartz substrate, an SUS substrate, or the like can be used as the substrate 500. Besides, though a substrate formed of a synthetic resin having flexibility, such as plastic typified by PET, PES, or PEN or acrylic, generally tends to have a lower heat resistance temperature than the above substrates, it can be utilized provided that it can resist against the treatment temperature in the manufacturing process.

[0066]

The base film 501 is provided in order to prevent alkaline-earth metal or

alkaline metal such as Na included in the substrate 500 from diffusing to a semiconductor film to cause an adverse effect on a characteristic of a semiconductor element. Therefore, it is formed using an insulating film such as silicon oxide, silicon nitride, or silicon nitride oxide which can prevent diffusion of alkaline metal or alkaline-earth metal to the semiconductor film. In this embodiment mode, a silicon nitride oxide film is formed to have a thickness of 10 ~ 400 nm (preferably 50 ~ 300 nm) by a plasma CVD method.

[0067]

It is noted that the base film 501 may be either a single layer or a stack of a plurality of insulating films. In addition, when a substrate including alkaline metal or alkaline-earth metal to some extent such as a glass substrate, a SUS substrate, or a plastic substrate is used, it is effective to provide a base film for the purpose of preventing diffusion of impurities; however, in the case where diffusion of impurities does not cause a significant problem, such as a quartz substrate, the base film is not necessarily provided.

[0068]

Next, a semiconductor film 502 is formed on the base film 501. The thickness of the semiconductor film 502 is set to 25 ~ 100 nm (preferably 30 ~ 60 nm). It is noted that the semiconductor film 502 may be either an amorphous semiconductor or a poly-crystalline semiconductor. In addition, not only silicon, but also silicon germanium can be used as a semiconductor. When silicon germanium is used, the concentration of germanium is preferably about 0.01 ~ 4.5 atomic%.

[0069]

Next, as shown in FIG. 4(B), the semiconductor film 502 is irradiated with the first and the second laser light using the laser irradiation apparatus of the present invention to perform crystallization.

[0070]

In this embodiment mode, as the first laser light, a YLF laser that has an energy of 6 W, an energy of one pulse of 6 mJ/p, an oscillation mode of TEM_{00}, a second harmonic (527 nm), a frequency of 1 kHz, and a pulse width of 60 ns is used. It is noted that the first laser light is processed through the optical system so that the first

beam spot formed on the surface of the semiconductor film 502 is made a rectangle having a length of 200 μm in minor axis, 3 mm in major axis, and an energy density of 1000 mJ/cm^2.

[0071]

In addition, in this embodiment mode, as the second laser light, a YAG laser that has an energy of 2 kW and a fundamental wave (1.064 μm) is used. Note that the second laser light is processed through the optical system so that the second beam spot formed on the surface of the semiconductor film 502 is made a rectangle having a length of 100 μm in minor axis, 3 mm in major axis, and an energy density of 0.7 MW/cm^2.

[0072]

Then, on the surface of the semiconductor film 502, irradiation is performed so as to overlap the first beam spot and the second beam spot and scanning is performed with the above two beams toward the direction indicated by a white arrow in FIG. 4(B). Since melting is caused by the first laser light, the absorption coefficient of the fundamental wave increases and the energy of the second laser light is easily absorbed by the semiconductor film. Then, the region melted by the irradiation with the second laser light which is continuous oscillation moves in the semiconductor film, so that crystal grains which grow continuously toward the scanning direction are formed. By forming the single-crystal grains extending long along the scanning direction, the semiconductor film in which the crystal grain boundary is rarely present at least in the channel direction of a TFT can be formed.

[0073]

Note that irradiation with the laser light may be performed in the atmosphere of an inert gas such as a rare gas, nitrogen, or the like. Accordingly, roughness of the surface of the semiconductor film by the irradiation with the laser light can be suppressed. Furthermore, the variation of the threshold value due to the variation of the interface state density can be suppressed.

[0074]

A semiconductor film 503 whose crystallinity is more enhanced is formed by irradiating the semiconductor film 502 with the laser light as described above.

[0075]

Next, as shown in FIG. 4(C), the semiconductor film 503 is patterned to form island shaped semiconductor films 507 ~ 509, and various kinds of semiconductor elements typified by TFTs are formed by using the island shaped semiconductor films 507 ~ 509.

[0076]

Next, although not illustrated, a gate insulating film is formed so as to cover the island shaped semiconductor films 507 ~ 509. For example, silicon oxide, silicon nitride, silicon nitride oxide, or the like can be used as the gate insulating film. As for its forming method, a plasma CVD method, a sputtering method, or the like can be used.

[0077]

Then, a conductive film is formed on the gate insulating film and patterned, so that a gate electrode is formed. Then, a source region, a drain region, in addition, an LDD region, and the like are formed by adding impurities which impart n-type or p-type conductivity to the island shaped semiconductor films 507 ~ 509 with use of the gate electrode or a resist which is formed and patterned as a mask.

[0078]

A TFT can be thus formed through a series of the above steps. It is noted that the method for manufacturing a semiconductor device of the present invention is not limited to the steps for manufacturing the TFT above after forming the island shaped semiconductor films. By employing the semiconductor film crystallized by the laser light irradiation method of the present invention as an active layer of the TFT, variation of the mobility between the elements, threshold value, and on-current can be suppressed.

[0079]

Note that the first laser light and the second laser light are not limited to the conditions of irradiation shown in this embodiment mode.

[0080]

For example, as the first laser light, a YAG laser that has an energy of 4 W, an energy of one pulse of 2 mJ/p, an oscillation mode of TEM_{00}, a second harmonic (532

nm), a frequency of 1 kHz, and a pulse width of 30 ns can be used. Alternatively, as the first laser light, for example, a YVO_4 laser that has an energy of 5 W, an energy of one pulse of 0.25 mJ/p, an oscillation mode of TEM_{00}, a third harmonic (355 nm), a frequency of 20 kHz, and a pulse width of 30 ns can be used. Further alternatively, as the first laser light, for example, a YVO_4 laser that has an energy of 3.5 W, an energy of one pulse of 0.233 mJ/p, an oscillation mode of TEM_{00}, a fourth harmonic (266 nm), a frequency of 15 kHz, and a pulse width of 30 ns can be used.

[0081]

In addition, as the second laser light, for example, a Nd:YAG laser that has an energy of 500 W and a fundamental wave (1.064 μm) can be used. Alternatively, as the second laser light, for example, a Nd:YAG laser that has an energy of 2000 W and a fundamental wave (1.064 μm) can also used.

[0082]

Moreover, a crystallization step using a catalytic element may be provided before crystallization with the laser light. As the catalytic element, nickel (Ni) is used; however, in addition to that, an element such as germanium (Ge), iron (Fe), palladium (Pd), tin (Sn), lead (Pb), cobalt (Co), platinum (Pt), copper (Cu), or gold (Au) can be used. When the crystallization step by the laser light is performed after the crystallization step using the catalytic element, the crystal formed in crystallization using the catalytic element remains without being melted by the irradiation with the laser light on the side nearer to the substrate, and the crystallization is promoted by using the crystal as a crystal nucleus. Therefore, the crystallization by the irradiation with the laser light is likely to be promoted uniformly from the side of the substrate to the surface of the semiconductor film. As compared with the case of only the crystallization step by the laser light, crystallinity of the semiconductor film can be further enhanced and roughness of the surface of the semiconductor film after the crystallization by the laser light can be suppressed. Thus, the variation of the characteristics of the semiconductor element, typically the TFT, which is to be formed later, can be suppressed and the off-current can be suppressed.

[0083]

It is noted that irradiation with the laser light may be performed to further

enhance the crystallinity after the catalytic element is added and heating treatment is performed to promote the crystallization. The step of the heating treatment may be omitted. Specifically, after adding the catalytic element, irradiation of irradiation with the laser light may be performed instead of the heating treatment in order to enhance the crystallinity.

[0084]

Note that this embodiment mode shows an example where the laser irradiation method of the present invention is used to crystallize the semiconductor film, but it can also be used to activate the impurity elements with which the semiconductor film is doped.

[0085]

The method for manufacturing a semiconductor device of the present invention can be applied to methods for manufacturing integrated circuits and semiconductor display devices. Especially, when it is applied to a semiconductor element such as a transistor provided in a pixel portion of a semiconductor display device such as a liquid crystal display device, a light emitting device in which a light emitting element typified by an organic light emitting element is provided in each pixel, a DMD (Digital Micromirror Device), a PDP (Plasma Display Panel), or an FED (Field Emission Display), the lateral fringe in a pixel portion, which results from the energy distribution of the laser light with which irradiation is performed, can be prevented from being viewed.

[0086]

[Embodiment]

Embodiments of the present invention are explained as follows.

[0087]

(Embodiment 1)

This embodiment shows one mode of the laser irradiation apparatus of the present invention.

[0088]

FIG. 5 shows a structure of the laser irradiation apparatus of this embodiment. In this embodiment, pulse oscillation first laser light having a wavelength of visible light or a shorter wavelength than visible light is oscillated from a laser oscillator 1520.

Further, continuous oscillation second laser light is oscillated from two laser oscillators 1500, 1501.

[0089]

Note that, in this embodiment, an excimer laser is used as the laser oscillator 1520, whose output energy of one pulse is 1 J and whose pulse width is 30 ns approximately, that is to say whose output per unit time is 30 MW. In addition, as both of the laser oscillators 1500, 1501, YAG lasers each of whose output energy is 10 kW are used.

[0090]

After the first laser light oscillated from the laser oscillator 1520 is reflected by a mirror 1523, it is condensed into a rectangular shape, an elliptical shape, or a linear shape through an optical system 1524, and a processing object 1514 is irradiated therewith. It is noted that in this embodiment, a shutter 1521 to obscure the first laser light is provided between the laser oscillator 1520 and the mirror 1523, but it is not necessarily provided. Moreover, the lens 1524 is acceptable as long as it can condense a beam spot into a linear shape, a rectangular shape, or an elliptical shape and homogenize the energy distribution.

[0091]

On the other hand, the second laser light oscillated from the laser oscillators 1500, 1501 enter beam expanders 1508, 1560 respectively. In this embodiment, shutters 1502, 1503 to obscure the second laser light are provided between the laser oscillators 1500, 1501 and the beam expanders 1508, 1560 respectively, but they are not necessarily provided.

[0092]

Then, by the beam expanders 1508, 1560, extension of the second laser light entered can be suppressed and in addition, the size of the sectional shape of the beam can be controlled.

[0093]

The second laser light output from the beam expanders 1508, 1560 are extended through the cylindrical lens 1509, 1561 respectively so that the sectional shape of the beams become a rectangular shape, an elliptical shape, or a linear shape. Then, the extended second laser light are reflected by mirrors 1510, 1562 respectively, and

together enter a lens 1511. The laser light entered are condensed into a linear shape by the lens 1511 and the processing object 1514 in a laser irradiation chamber 1513 is irradiated therewith. In this embodiment, a cylindrical lens is used as the lens 1511, but any lens is acceptable as long as it can make the beam spot into a rectangular shape, an elliptical shape, or a linear shape.

[0094]

In this embodiment, the mirror 1523 and the optical system 1524 correspond to an optical system dealing with the first laser light. On the other hand, the beam expanders 1508, 1560, the cylindrical lenses 1509, 1561, and the mirrors 1510, 1562 correspond to an optical system dealing with the second laser light. With these two optical systems, the first beam spot formed by the first laser light on the surface of the processing object 1514 and the second beam spot formed by the second laser light on the surface of the processing object 1514 can be overlapped.

[0095]

FIG. 7 shows an example of the shape and the layout of each beam spot utilized in the laser irradiation apparatus shown in FIG. 5. In FIG. 7, 1570 corresponds to the first beam spot and 1571, 1572 correspond to the second beam spots respectively. In FIG. 7, the second beam spots 1571 and 1572 are overlapped partially with each other so that the major axes thereof correspond to each other. Further, the first beam spot 1570 is overlapped so as to cover the second beam spots 1571, 1572 completely.

[0096]

In this embodiment, a length L_{X1570} in a direction of the minor axis of the first beam spot 1570 is set to 400 μm, a length L_{y1570} in a direction of the major axis is set to 110 mm, and the energy density is set to about 25 MW/cm^2. When calculated into the energy density per a pulse, about 100 ~ 1000 mJ/cm^2 is appropriate. In addition, a length L_{X1571} in a direction of the minor axis of the second beam spot 1571 is set to 200 μm, a length L_{y1571} in a direction of the major axis is set to 60 mm, and the energy density is set to 0.1 MW/cm^2. Furthermore, a length L_{X1571} in a direction of the minor axis of the second beam spot 1571 is set to 200 μm, a length L_{y1571} in a direction of the major axis is set to 60 mm, and the energy density is set to 0.1 MW/cm^2. Furthermore, the second beam spots 1571, 1572 are overlapped for 20 mm with each other so that the

length of chained major axes of the second beam spots 1571, 1572 may become 100 mm.

[0097]

In this manner, by synthesizing a plurality of the second laser light, the region where the first laser light and the second laser light are overlapped can be enlarged, and the proportion of the region whose crystallinity is low in the whole region irradiated with the laser light can be decreased.

[0098]

Note that, in this embodiment, two laser oscillators are used to irradiate the processing object with two systems of the second laser light, but the present invention is not limited to this, and a plurality of three or more systems of the second laser light may be used. In addition, a plurality of systems may be employed for the first laser light.

[0099]

In the laser irradiation chamber 1513, the processing object 1514 is mounted on a stage 1515, and the position of the stage 1515 is controlled by three uniaxial robots 1516 ~ 1518. Specifically, the stage 1515 can be rotated in the horizontal plane by the uniaxial robot 1516 for the ϕ axis. In addition, the stage 1515 can be moved in the X-axis direction in the horizontal plane by the uniaxial robot 1517 for the X axis. Furthermore, the stage 1515 can be moved in the Y-axis direction in the horizontal plane by the uniaxial robot 1518 for the Y axis. The operation of a means for controlling each position is controlled in a central processing device 1519.

[0100]

An aggregation of the crystal grains extending long along the scanning direction can be formed by scanning the processing object in the X direction as performing irradiation with the linear beam spot extending long in the Y-axis direction. The scanning speed may be set to 10 ~ 2000 mm/s for example, preferably 100 ~ 1000 mm/s, but the optimum range of the scanning speed increases or decreases depending on the conditions such as the thickness, the material, or the like of the semiconductor film. Thus the single-crystal grains growing in the scanning direction can be formed in a packed state in the region that extends in the scanning direction having a width of 100 mm. The width of this region where the crystal grains growing in the scanning

direction are packed is about 100 times as broad as the case of a conventional technique in which crystallization is performed by using only the continuous oscillation laser light simply.

[0101]

It is noted that a monitor 1512 using a light-receiving element such as a CCD may be provided in order to recognize the exact position of the processing object 1514 as shown in this embodiment.

[0102]

(Embodiment 2)

The structure of the pixel in the light emitting device, which is one of the semiconductor devices formed by using the laser irradiation apparatus of the present invention, is explained with FIG. 6.

[0103]

In FIG. 6, a base film 6001 is formed on a substrate 6000, and a transistor 6002 is formed on the base film 6001. The transistor 6002 includes an active layer 6003, a gate electrode 6005, and a gate insulating film 6004 interposed between the active layer 6003 and the gate electrode 6005.

[0104]

A poly-crystalline semiconductor film crystallized by using the laser irradiation apparatus of the present invention is used for the active layer 6003. It is noted that not only silicon but also silicon germanium may be used for the active layer. In the case of using silicon germanium, it is preferable that the concentration of germanium be about 0.01 ~ 4.5 atomic%. In addition, silicon to which carbon nitride is added may be also used.

[0105]

Moreover, silicon oxide, silicon nitride, or silicon oxynitride can be used as the gate insulating film 6004. In addition, a film in which those are laminated, for example, a film in which SiN is laminated on SiO_2 may be used as the gate insulating film. Furthermore, an element selected from Ta, W, Ti, Mo, Al, and Cu, or an alloy material or a compound material containing the element above as its main component can be used as the gate electrode 6005. Moreover, a semiconductor film, typically a poly-crystalline silicon film which is doped with an impurity element such as

phosphorus, may be used. In addition, not only a conductive film of a single layer but also a conductive film of a plurality of layers may be used.

[0106]

In addition, the transistor 6004 is covered with a first interlayer insulating film 6006, and a second interlayer insulating film 6007 and a third interlayer insulating film 6008 are laminated on the first interlayer insulating film 6006. As the first interlayer insulating film 6006, a film of silicon oxide, silicon nitride, or silicon oxynitride with a single layer or a laminated layer by using a plasma CVD method or a sputtering method can be used.

[0107]

As the second interlayer insulating film 6007, nonphotosensitive acrylic can be used. As the third interlayer insulating film 6008, a film through which a substance that causes promotion of deterioration of a light emitting element, such as moisture or oxygen, does not easily penetrate as compared with other insulating films is used. Typically, it is desirable to use a DLC film, a carbon nitride film, a silicon nitride film formed by an RF sputtering method, or the like.

[0108]

In FIG. 6, 6010 denotes an anode, 6011 denotes an electroluminescent layer, and 6012 denotes a cathode. A portion where the anode 6010, the electroluminescent layer 6011, and the cathode 6012 overlap corresponds to a light emitting element 6013. The transistor 6002 is a driver transistor that controls a current supplied to the light emitting element 6013, and is connected directly or serially through another circuit element to the light emitting element 6013. The electroluminescent layer 6011 has a structure of only a luminous layer or a structure in which a plurality of layers including a luminous layer are laminated.

[0109]

The anode 6010 is formed on the third interlayer insulating film 6008. In addition, an organic resin film 6014 which is used as a partition wall is formed on the third interlayer insulating film 6008. The organic resin film 6014 has an opening 6015, and the light emitting element 6013 is formed by overlapping the anode 6010, the electroluminescent layer 6011, and the cathode 6012 in the opening.

[0110]

Further, a protective film 6016 is formed over the organic resin film 6014 and the cathode 6012. As well as the third interlayer insulating film 6008, as the protective film 6016, a film through which a substance that causes promotion of deterioration of a light emitting element, such as moisture or oxygen, does not easily penetrate as compared with other insulating films, for example a DLC film, a carbon nitride film, or a silicon nitride film formed by an RF sputtering method is used.

[0111]

In addition, it is desirable that the end of the opening 6015 in the organic resin film 6014 be rounded so that the electroluminescent layer 6011 formed so as to partially overlap on the organic resin film 6014 does not have a hole in the end thereof. To be more specific, it is desirable that the radius of curvature of the curve line drawn by the section of the organic resin film in the opening be about 0.2 ~ 2 μm. With the above structure, the coverage of an electroluminescent layer and a cathode that are formed later can be favorable, and the anode 6010 and the cathode 6012 can be prevented from being short-circuited in the hole formed in the electroluminescent layer 6011. Moreover, by easing stress of the electroluminescent layer 6011, defects called a shrink which is a decreasing of a light emitting region can be reduced, and reliability can be enhanced.

[0112]

In addition, FIG. 6 shows an example in which a positive type photosensitive acrylic resin is used as the organic resin film 6014. A photosensitive organic resin is classified into a positive type in which a portion where an energy line such as light, an electron, or an ion is exposed is removed, and a negative type in which a portion that is exposed remains. In the present invention, a negative type organic resin film may also be used. Moreover, the organic resin film 6014 may be formed using photosensitive polyimide. When the organic resin film 6014 is formed using negative type acrylic, the end of the opening 6015 becomes to have a sectional shape of a letter of S. At this time, it is desirable that the radius of curvature in tan upper end portion and a lower end portion of the opening be 0.2 ~ 2 μm.

[0113]

A transparent conductive film can be used as the anode 6010. Not only ITO,

but also a transparent conductive film in which indium oxide is mixed with 2 ~ 20 % zinc oxide (ZnO) may be used. In FIG. 6, ITO is used as the anode 6010. On the other hand, as the cathode 6012, another known material can be used as long as it is a conductive film having a low work function. For example, Ca, Al, CaF, MgAg, AlLi, or the like is desirable.

[0114]

It is noted that, in FIG. 6, a structure in which the side of the substrate 6000 is irradiated with light emitted from the light emitting element; however, a light emitting element having a structure in which light is transferred to the side opposite to the substrate may be employed. In addition, in FIG. 6, the transistor 6002 and the anode 6010 of the light emitting element are connected, but the present invention is not limited to this structure, and the transistor 6002 and the cathode 6001 of the light emitting element may be connected. In this case, the cathode is formed on the third interlayer insulating film 6008. In addition, it is formed using TiN or the like.

[0115]

It is noted that, actually, after completion up to FIG. 6, it is preferable to perform packaging (sealing) with a protective film (a laminated film, an ultraviolet cured resin film, or the like) or a transparent cover member which has high airtightness and causes little degasification, in order to prevent further exposure to external air. At that time, the reliability of an OLED is enhanced when the inside of the cover member is made an inert atmosphere or a hygroscopic material (barium oxide, for example) is arranged in the inside thereof.

[0116]

It is noted that the light emitting device is described as an example of semiconductor devices in this embodiment, but the semiconductor device formed by using the manufacturing method of the present invention is not limited to this.

[0117]

[Effect of the Invention]

According to the present invention, the absorption coefficient of a fundamental wave is increased by performing irradiation with the first laser light having a wavelength of visible light or a shorter wavelength than visible light which is easy to be absorbed by the semiconductor film to melt the semiconductor film. By employing

pulse oscillation for the first laser light, the area of the beam spot can be significantly enlarged than the case of the continuous oscillation. Further, by performing irradiation with the second laser light having a fundamental wave in a state of being melted, the second laser light is absorbed efficiently by the semiconductor film whose absorption coefficient of a fundamental wave is increased. As a result, since the major axis of the beam spot can be made long, throughput of the laser crystallization can be enhanced and it is effective for easing the design rule.

[0118]

It is noted that the region which is melted by the first laser light and whose absorption coefficient is increased can be moved by performing scanning with the second laser light, and the region where the crystal grains growing in the scanning direction are packed can be formed. Moreover, even after irradiation with the first laser light is over, the melted region whose absorption coefficient is increased can be moved in one direction to some extent by scanning.

[0119]

Furthermore, since a fundamental wave is employed as the second laser beam, it is not necessary to consider the resistance of a non-linear optical element which is used to perform conversion into a harmonic, and a laser having considerably high output, for example one whose energy is 100 times or more as high as a harmonic can be employed as the second laser light. Further, cumbersomeness of maintenance of the non-linear optical element due to the change of its quality disappears. Especially, an advantage of a solid laser, that a maintenance-free state can be kept long, can be utilized.

[Brief Description of the Drawings]

[FIG. 1] Drawings showing magnitude relationships of beam spots.

[FIG. 2] A drawing showing a structure of a laser irradiation apparatus of the present invention.

[FIG. 3] A drawing showing a scanning route of a processing object in a laser irradiation method of the present invention.

[FIG. 4] Drawings showing a method for manufacturing a semiconductor device.

[FIG. 5] A drawing showing a structure of a laser irradiation apparatus of the present invention.

[FIG. 6] A sectional view of a light emitting device manufactured by using a laser irradiation apparatus of the present invention.

[FIG. 7] A drawing showing the shape of a beam spot used in the laser irradiation apparatus shown in FIG. 5.

[FIG. 8] A drawing showing a relationship between a wavelength of laser light and an absorption coefficient.

[Name of Document] Abstract

[Summary]

[Problem] It is an object to provide a laser irradiation apparatus for enlarging an area of a beam spot and reducing the proportion of a region with low crystallinity. It is also an object to provide a laser irradiation apparatus for enhancing throughput with use of continuous oscillation laser light. Furthermore, it is an object of the present invention to provide a laser irradiation method and a method for manufacturing a semiconductor device which use the laser irradiation apparatus.

[Solving Means] A region melted by pulse oscillation first laser light having of a harmonic is irradiated with continuous oscillation second laser light. Specifically, the first laser light has a wavelength which is approximately equal to or shorter than that of visible light (approximately 830 nm or less). Since the first laser light melts a semiconductor film, the absorption coefficient of the second laser light to the semiconductor film increases drastically and the second laser light becomes easy to be absorbed by the semiconductor film.

[Selected Drawing] FIG. 2